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FAR FIELD STUDIES-COMPARITIVE ANALYSIS
OF UPPER MANTLE Q AND OTHER
GEOPHYSICAL DATA ON THE EURASIAN
CONTINENT

Stephen A. Alsup

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**FAR FIELD STUDIES - COMPARATIVE ANALYSIS OF UPPER MANTLE Q AND OTHER
GEOPHYSICAL DATA ON THE EURASIAN CONTINENT**

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Prepared by
Stephen A. Alsup

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ABSTRACT

A review and comparative analysis of published reports providing research data within Eurasia concerning the upper mantle geophysics shows the following:

- High upper mantle P-wave velocities, early relative teleseismic P-wave delays, low heat flow, absence of low-resistivity upper mantle layers, and low P-wave absorption are representative of the shield, platform, and massif regions of Eurasia.
- Opposite relative values of the parameters given above correspond to the active structural and volcanic regions, most notably the Sea of Okhotsk - Sea of Japan - Kamchatka - Kuril-Japan region, around Lake Baykal, and along the Southern to Southwestern border of the USSR.

Maps and brief discussions of the parameters mentioned, including a regional estimate of upper mantle Q for P-waves, are given in the report.

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SECTION I

INTRODUCTION

Characteristics of seismic wave propagation within Eurasia are influenced by geophysical parameters along the propagation path which are not directly observable by stations collecting recordings outside or around the borders of the Eurasian land mass. There are, however, translations of scientific reports or reports prepared in English which concern measurements and interpretation of geophysical data collected in Eurasia which may offer some insight into factors which are known to represent or have influence on seismic wave propagation conditions. This report includes the results of a literature survey for collecting pertinent Eurasian geophysical data into a brief reference document which can serve as one guideline for interpretation of anomalous signal features or identify regions or paths which may cause anomalous signal features or identify regions or paths which may cause anomalous signal behaviour.

The sources of information for the data included here are not considered a comprehensive or complete list of every available report or publication. An effort has been made, however, to include as much information as possible in a brief time, and to include references which give information for regions which may not have had widespread scientific attention because of unique interest or character to the local research agencies. Broad geographical coverage was considered a goal, even though the information available might be limited.

Geophysical parameters of interest in this survey, in order of their occurrence in the paragraphs below, include the general geotectonic settings of Eurasia, upper mantle P-wave velocities, teleseismic P-wave

travel times, heat flow, magnetotelluric surveys, and upper mantle P-wave absorption factors. The interrelationships of these factors, as well as the numerical values reported or calculated for each, are discussed briefly in each section. A location map for the measurement; or calculated value is also given for each subject discussed. A list of cited reports and reports of general interest to geophysical problems in Eurasia is included at the end of the report.

SECTION II

GENERAL GEOTECTONICS

Figure 1 outlines geotectonic regions of Eurasia. Patterns representing different elements are not detailed to any extent in the figure because of the large region displayed, and they are representative of the general distribution of geo-structural elements. These patterns should be viewed as guides only for regional analysis in terms of geophysical parameters discussed later. Data on the map were drawn mainly from Khain and Muratov (1969), Lubimova and Polyak (1969), and Horai and Uyeda (1969).

The major part of northern Eurasia consists of broad stable crustal platforms with several extensive exposed shield areas and stable undeformed massifs. With the exception of the southwestern, southern, and eastern border regions, all of the USSR is similar in geotectonic characteristic to the central U. S. and eastern Canada. Geophysical parameters are, therefore, expected to be similar in terms being able to extrapolate these data from one continent to another.

The main mass of China is typified by more widespread structural activity over much of the geologic time scale, with faulting and folding elements identified from the Paleozoic through Cenezoic. Nearly all of China-Mongolia was involved in Alpine-related structural movements. Counterparts of this structural activity are found in the Appalachian mountain chain of the eastern United States. The very strong Alpine type of deformation is confined primarily to the Himalyan Mountains, however, and the main central region of China is expected to be represented by geophysical characteristics similar to those found in the mountainous regions of the eastern U. S.

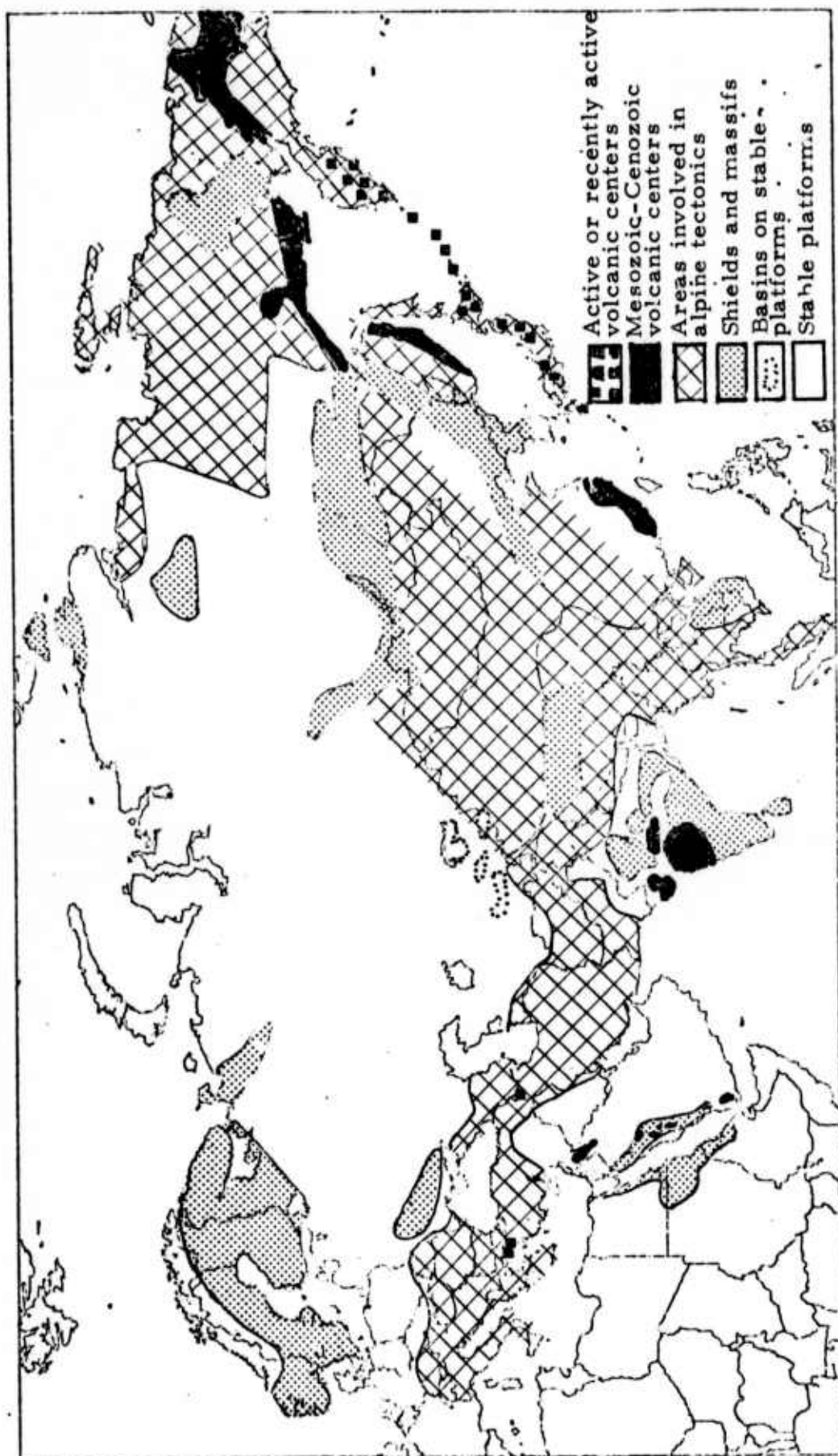


FIGURE 1
GENERALIZED TECTONIC ELEMENT MAP OF EURASIA

Regions of Mesozoic-Cenozoic volcanic activity are confined mostly to the peripheral areas of the continent (western and southern). These are of interest in terms of potentially anomalous effect upon seismic propagation, as are the active or recently-active volcanic regions indicated on the figure. Several of the smaller structural basins on the main platforms are also indicative of anomalous conditions which are of interest in explaining seismic signal behavior.

SECTION III

UPPER MANTLE P-WAVE VELOCITIES (Pn)

Velocity of compressional waves in the upper mantle beneath the shield-platform regions of the USSR are high (8.0 km/sec or greater) and in keeping with the high velocities observed beneath similar areas in the U.S. There are insufficient data to form a basis for contouring the Pn velocities similar to Herrin (1969), but extrapolation on the basis of the geotectonics may be reasonable. Since long, continuous refraction profiles have been made in the platform regions and published results show velocities of Pn of 8.0 km/sec or greater (Figure 2), it is likely that such velocities are representative for virtually all of the regions indicated as platform-massif-shield on Figure 1. Other geophysical data discussed in later sections show no anomalous changes over parts of the regions not covered by the refraction profiles, and therefore offer no reason to limit an estimate of high velocity only to those areas where profiles have been obtained.

Low Pn velocities have been clearly indicated by profiles in the Hungarian Basin (7.81 km/sec), in western Turkmenia at the southeast shore of the Caspian Sea (7.8-7.9 km/sec), parts of Tadzhik (7.7 km/sec) and beneath Lake Baykal (7.81 km/sec). Details of Pn velocity in the Sea of Okhotsk and in the Kuril-Kamchatka regions have been published, but the scale of mapping here prevents display in the figure. Low upper mantle velocities in the Kuril-Kamchatka region are typically found in a band paralleling the structural trend approximately centered beneath the island chain. Lateral extent of the band is variable, and it apparently represents a zone of low velocity above a descending lithospheric plate similar to that envisioned in island arcs by LePichon (1968); and Isacks, et al (1968).

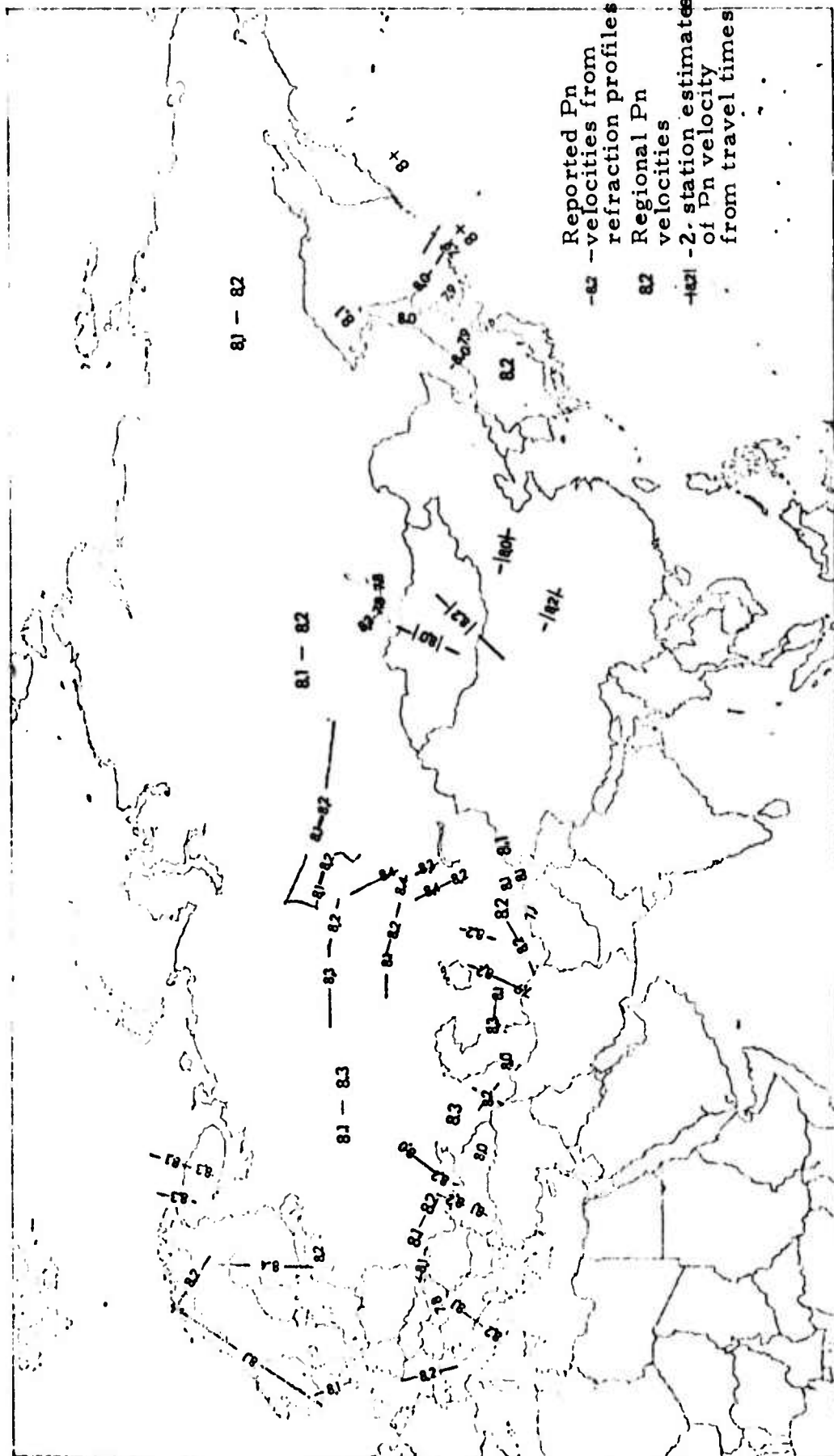


FIGURE 2
UPPER MANTLE Pn VELOCITIES BENEATH EURASIA

No published Pn velocities were found for China in the literature search, but several estimates on Figure 2 which are based upon reported travel times from a series of earthquakes in northern Tsinghai Province (37.0°N , 95.8°E) to recording stations in China, Mongolia, and the Lake Baykal area in Russia. These upper mantle velocities are tentative since they were derived by simply dividing the distance between two stations by the difference in signal arrival times reported by Golenetskii and Medvedeva (1965): there is no particular indication of low upper mantle velocity except perhaps in the Lake Baykal area. Bugayevskiy, et al (1970), also found evidence of low velocities in the upper mantle beneath northern Mongolia and the Sayan Mountain block to the south and west (as far as 90°E longitude). Their evidence is based upon late P-wave arrivals from regional and near-teleseismic sources in China and Russia recorded at stations along a profile from Lake Balkash to Lake Baykal: ray paths passing beneath the Mongolian and Sayan regions have significant slowness compared to paths passing beneath other Eurasian regions at similar epicentral distances.

The main sources of Pn velocities for Eurasia shown in Figure 2 include a series of technical paper translations (Ed. Shishkevish, 1970) and a survey paper by Kosminskaya, et al (1969).

SECTION IV

TELESEISMIC P-WAVE DELAYS

Variance of observed travel times from some standard model of travel time versus distance and depth is a topic which has been discussed by many seismologists, including very detailed observations in the United States (Herrin, 1969; Archambeau, et al 1969; Evernden, 1970). In such studies, it is commonly observed that travel times to recording stations over shield and platform regions are less than the times to stations over more structurally disturbed or structurally active regions at the same epicentral distance. Since travel time is one of the most critical factors used to describe seismic sources, the details of teleseismic P-wave delays are important in describing source region characteristics. The delays also provide important corroborative evidence for the characteristics of other geophysical observations.

Three main sources of information about teleseismic P-delays were used for construction of a tentative P-delay map of Eurasia (Figure 3). Worldwide "standard" travel times given by Herrin (1968) for surface focus events were used as a model, and the P-delays shown are for observed minus "standard" times (a negative residual indicates signal arrivals early in comparison to the standard).

Mean station corrections for 93 Eurasian stations given by Herrin and Taggart (1968), calculated residuals from data given for 45 stations reported by Golenetskii and Medvedeva (1965), and calculated residuals for 17 stations observed by Kondorskaya and Slavina (1969) were used to construct the P-wave delay map in Figure 3. All stations of the three sets are common to the Herrin list with the exception of nine reported by Golenetskii and Medvedeva (1965), and are reported by Kondorskaya and Slavina (1969). Stations

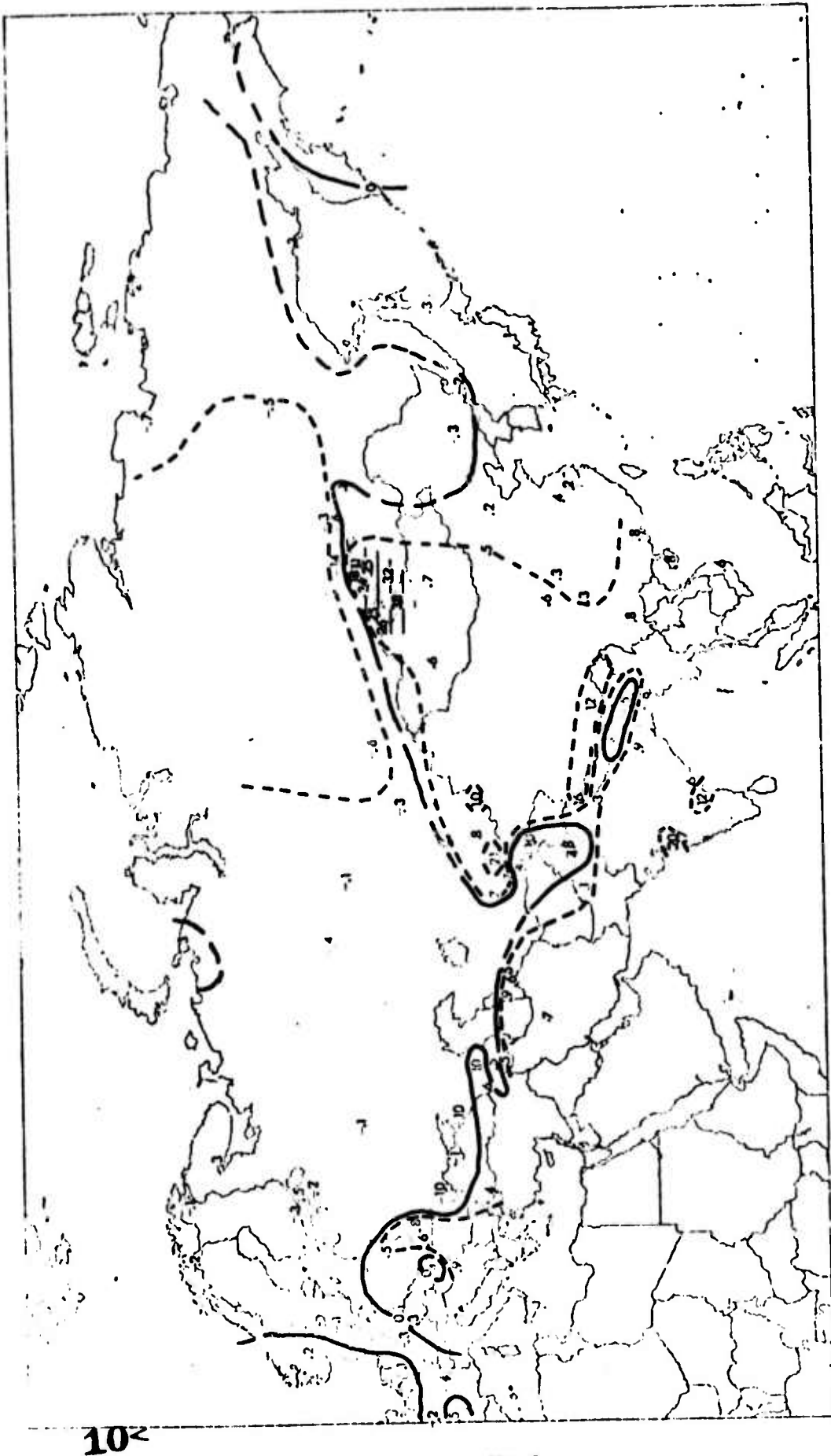


FIGURE 3
P-DELAYS IN EURASIA
(OBSERVED MINUS HERRIN 1968 SURFACE FOCUS TIMES, IN SECONDS)

and residuals are given in Table I. No consideration is given to azimuthal effects in the tabulation or on the figure.

For the most part, the residuals from all of the sets agree, but significant differences do appear. The Herrin data were considered as a primary control to construct the figure of P-delays, and the Russian observations were used only when no Herrin data were available, or when the Herrin data were based on very few source events and the results disagree with all of the other geophysical evidence.

The greatest difference in P-delays is noted in the Lake Baykal area where low Pn velocity and greatest upper mantle P-velocity slowness was noted. With the exception of the Herrin and Taggart (1968) residuals (0.2 second at Irkutsk) all of the remaining residuals are 1.0 second or greater, and several exceed 3.0 seconds. Strongly positive residuals are also evident over the core region of the Himalayas, along the west coast of India (very high heat flow--see next section), in Tadzhik southwest of Lake Balkash, along the southeast border of the Caspian Sea, and in the Hungarian Basin.

Most of China has moderately positive P-delays (with the exception of the Himalayas region), and the major part of the Russian and European-Scandinavian regions show moderately negative (early) P-wave arrivals. Earliest P-wave arrivals are shown north of the Black Sea, in the Hindu Kush, and immediately along the Himalayan front in India.

P-delays in the Kamchatka-Kuril-Japan region and around the peripheries of the Sea of Okhotsk and Sea of Japan are moderately positive (up to +0.7 seconds) to moderately negative (as early as -0.3 seconds). Japanese stations reported by Herrin and Taggart (1968) have a range from +0.9 to -0.5 seconds. Because of the large-scale structural elements along the Kamchatka-Kuril-Japan trends, the delays could be expected to show strong azimuthal preferences and are very likely locally variable. Contours of the P-delays in the eastern part of the map should be considered highly subjective for this reason.

TABLE I
TELESEISMIC P-WAVE DELAY TIMES (OBSERVED MINUS HERRIN 1968
SURFACE FOCUS TIMES) AND HEAT FLOW IN EURASIA.
(PAGE 1 OF 4)

STATION	TRAVEL TIMES Obs. - Calc.			HEAT FLOW $\mu\text{cal}/\text{cm}^2/\text{sec}$
	Herrin 68	Golenetskii and Medvedeva	Kondorskaya and Slavina	
<u>RUSSIA</u>				
Alma-Ata	0.1		-0.6	.1.3
Amderma	0.3			(low)
Andizan	1.0			
Apatity	-0.3	-0.2	-0.9	0.8
Arshan			2.5	2.1-3.8
Ashkabad	0.9	0.2		
Bakurani	0.6		0.7	1.2
Barguzin		1.1		2.2
Bayandai		1.8		2.4
Bodaibo	-0.2	-0.6	-0.3	
Chara		0.7		
Frunze	0.7	0.9	0.8	1.1
Garm	-0.4			
Goris	0.5	4.0		1.2
Irkutsk	0.2	3.8		0.9
Kabansk		2.5		2.1-3.0
Kheis	0.8	-0.4		
Khorog	0.9	2.0		
Kirovabad	-0.5		-0-	0.7
Kishinev	-1.0			0.7
Kizyl-Aravat	0.9			
Kayakhta		3.2		
Kurilsk	0.4			2.0-3.6
Lvov	0.7	0.8		1.2
Magadan	0.3			
Makhachkala	1.0			
Mondy			2.6	2.1-3.8
Moscow	-0-	0.2		1.0
Namangari	2.1			2.0
Nelyati		-0.6		

TABLE I
TELESEISMIC P-WAVE DELAY TIMES (OBSERVED MINUS HERRIN 1968
SURFACE FOCUS TIMES) AND HEAT FLOW IN EURASIA
(PAGE 2 OF 4)

STATION	TRAVEL TIMES Obs. - Calc.			HEAT FLOW $\mu\text{cal/cm}^2/\text{sec}$
	Herrin 68	Golenetskii and Medvedeva	Kondorskaya and Slavina	
Nizhni-Angarsk		-1.4		
Petropavlosk	0.1		-0.2	1.0
Petropavlosk-Kamchutsky		-0-		
Poulkova	-0.1			1.0
Semipalatinsk	-0.3	1.4	-0.2	(1.2)
Semifero ¹	-0.1			1.0
Sochi	-1.0			1.0
Stalinbad	0.6	0.7		
Sverdlosk	-0.2	0.6	-0.6	(1.0)
Tashkent	0.7	-1.1		(1.0)
Tblisi	1.0	1.9		1.5
Tiksi	-0.7	-2.7	-1.3	
Tupik		0.1		
Tyrgan		3.4		3.4
Uglegorsk	0.7			
Uzghorod	0.5	0.6	1.2	(1.0)
Vannovskaya	0.6	0.6	0.6	
Vladivostok	-0.2			
Vyborg	-0.5		-2.2	0.7
Yeltsovka	-0.6			(0.9)
Yuzhno-Sakhalinsk	0.3	-1.0	0.2	(1.1)
Yakutsk	-0.5	-1.5	-1.0	0.9-1.2
Zakamensk		3.8		5.1-3.8
<u>CHINA, MONGOLIA, NEPAL</u>				
Altai		(1.5)		
Baotou (Paotow)	0.5	(-1.5)		
Canton	0.8	-0.7		
Changchun	-0.4	-0.2		
Chatra	-0.6			

TABLE I
TELESEISMIC P-WAVE DELAY TIMES (OBSERVED MINUS HERRIN 1968
SURFACE FOCUS TIMES) AND HEAT FLOW IN EURASIA
(PAGE 3 OF 4)

STATION	TRAVEL TIMES			HEAT FLOW $\mu\text{cal}/\text{cm}^2/\text{sec}$
	Obs. - Calc.			
	Herrin 68	Golenetskii and Medvedeva	Kondorskaya and Slavina	
Chengtu	0.3	(6.0)		
Esen Boulak	0.6			
Hong Kong	0.8			
Kunming	0.8	1.9		
Lanchow	0.6	(-2.2)		
Lhasa	1.2	4.9		
Nanking	0.4	1.2		
Oulan Bator	0.7	-0.1		
Peking	0.2	(2.5)		
Sian	0.5	(-3.0)		
Zose (Tsose)	0.2	-0.9		
<u>INDIA, PAKISTAN, BURMA,</u>				
<u>VIETNAM, ETC.</u>				
Bokaro	0.9			(2.1)
Bombay	0.2			
Calcutta	1.7			(1.5)
Chi Hogong	0.8			
Dehra Dun	1.6			
Hyderabad	1.2			
Istanbul	0.4			0.9
Lahore	-0.4			
Madras	0.6			
New Delhi	0.3			1.6
Nhatrang	0.6			
Poona	0.7			
Que Ha	0.1			
Shillong	-0.5			
Shiraz	-0.6			
Teheran	0.7			
Vishakhapatnam	2.1			(2.0)
Warsak	-0.8			

TABLE I
TELESEISMIC P-WAVE DELAY TIMES (OBSERVED MINUS HERRIN 1968
SURFACE FOCUS TIMES) AND HEAT FLOW IN EURASIA.
(PAGE 4 OF 4)

STATION	TRAVEL TIMES Obs. - Calc.			HEAT FLOW $\mu\text{cal}/\text{cm}^2/\text{sec}$
	Herrin 68	Golenetskii and Medvedeva	Kondorskaya and Slavina	
<u>EUROPE, SCANDANAVIA</u>				
Bensburg	0.1			(1.0)
Belgrade	0.9			
Besancon	-0.4			
Bratislovia	-0-			1.2
Bucharrest	2.5			
Budapest	-0.4			2.0
Cheb	0.3			1.3
Clermont Ferand	0.5			
Foliniere	-0.2			
Goteberg	-0.1			0.8
Helsinki	-0-			
Jena	-0.3			
Korgsberg	0.2			
Krakow	-0-			
Muenster-Westfallen	0.5			(1.4)
Nuimyarui	-0.3			0.8
Oslo	-0-			
Sodan Kayla	-0.2			(0.8)
Uppsula	-0.6			
Warsaw	0.6			(1.7)

SECTION V

MEASURED HEAT FLOW

Heat flow measurements in Eurasia are relatively numerous (with the exception of a lack of reports for China), but are quite often strongly biased toward locales of special interest or curiosity. Extrapolation of the available data to lateral contours is not considered to be justified for that reason except where systematic investigations have been reported (Sea of Okhotsk, and Sea of Japan). Figure 4 includes a plot of heat flow values reported by Lyubimova, et al (1964), Boldizar (1964), Simmons and Horai (1968), Lyubimova and Polyak (1969), and Lyubimova (1970). As much data as possible was plotted on the figure, but where an extremely large number of values were reported, an average (or "typical") value is plotted on the figure. Regions where measured heat flows exceed 2 HFU (Heat Flow Units = microcalories/cm²/second) or could be expected to have values of this order are shown in stippling on Figure 5.

The broadest areas of high heat flow are obviously in eastern Eurasia, particularly along the island chain and in the Sea of Okhotsk and Sea of Japan. Some parts of the region do show lower heat flow according to systematic gridwork sampling, and the variability seems consistent with the strong structural activity. Other areas of high heat flow include the southern and eastern parts of Lake Baykal (possible extending beneath northern Mongolia and the Sayan Mountains by implication of P-wave travel times), but low heat flow is evident immediately over the rest of the lake area. Several of the small basins on the regional platform southwest of Lake Balkash (in Tadzhik) show abrupt increase in low regional heat flow over the basin areas (with accompanying low Pn velocity). Two "hot spots" along the Indian coastlines

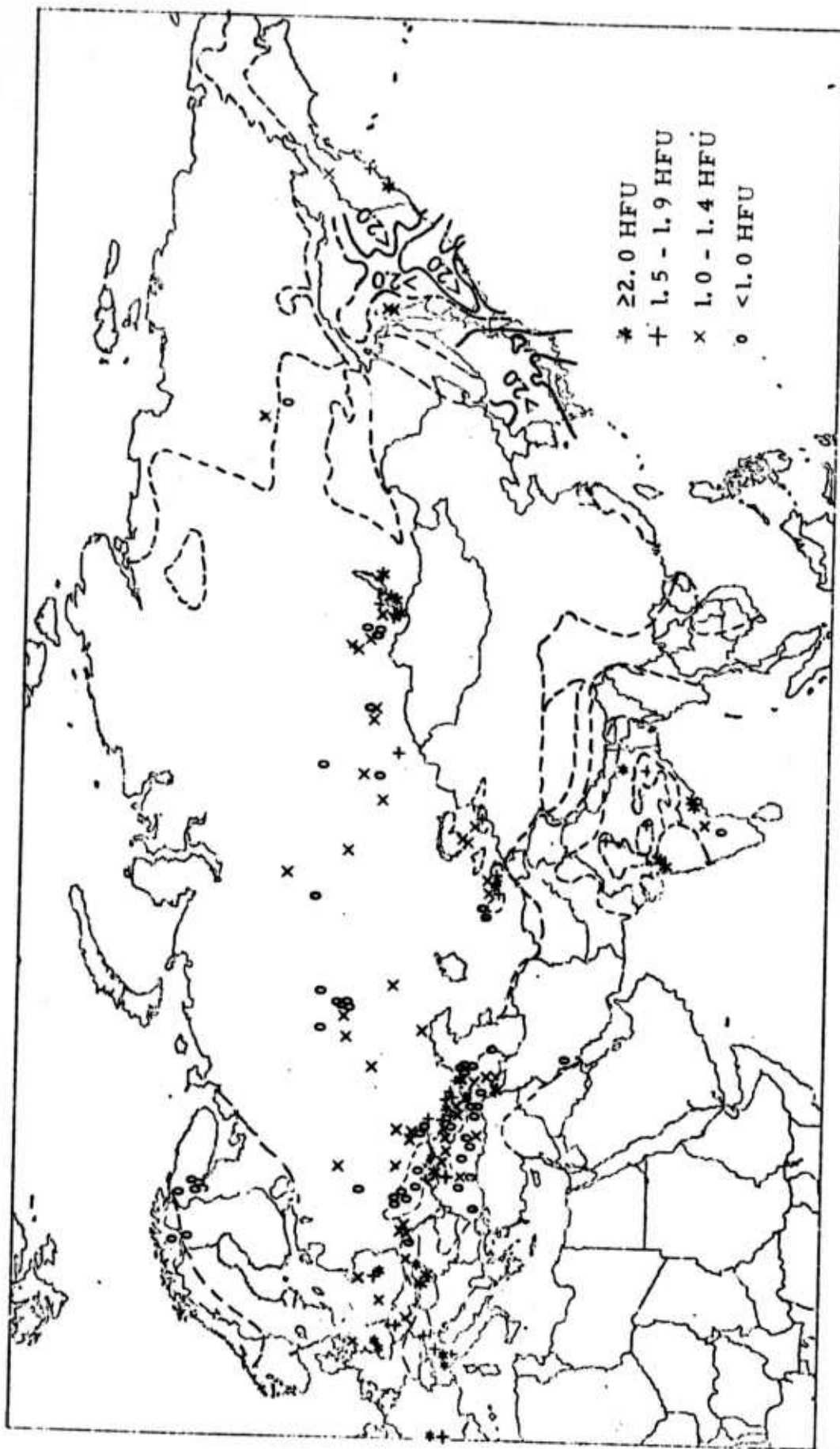


FIGURE 4
 HEAT FLOW IN EURASIA
 (1 HFU = MICROCALORIE/CM²/SEC)

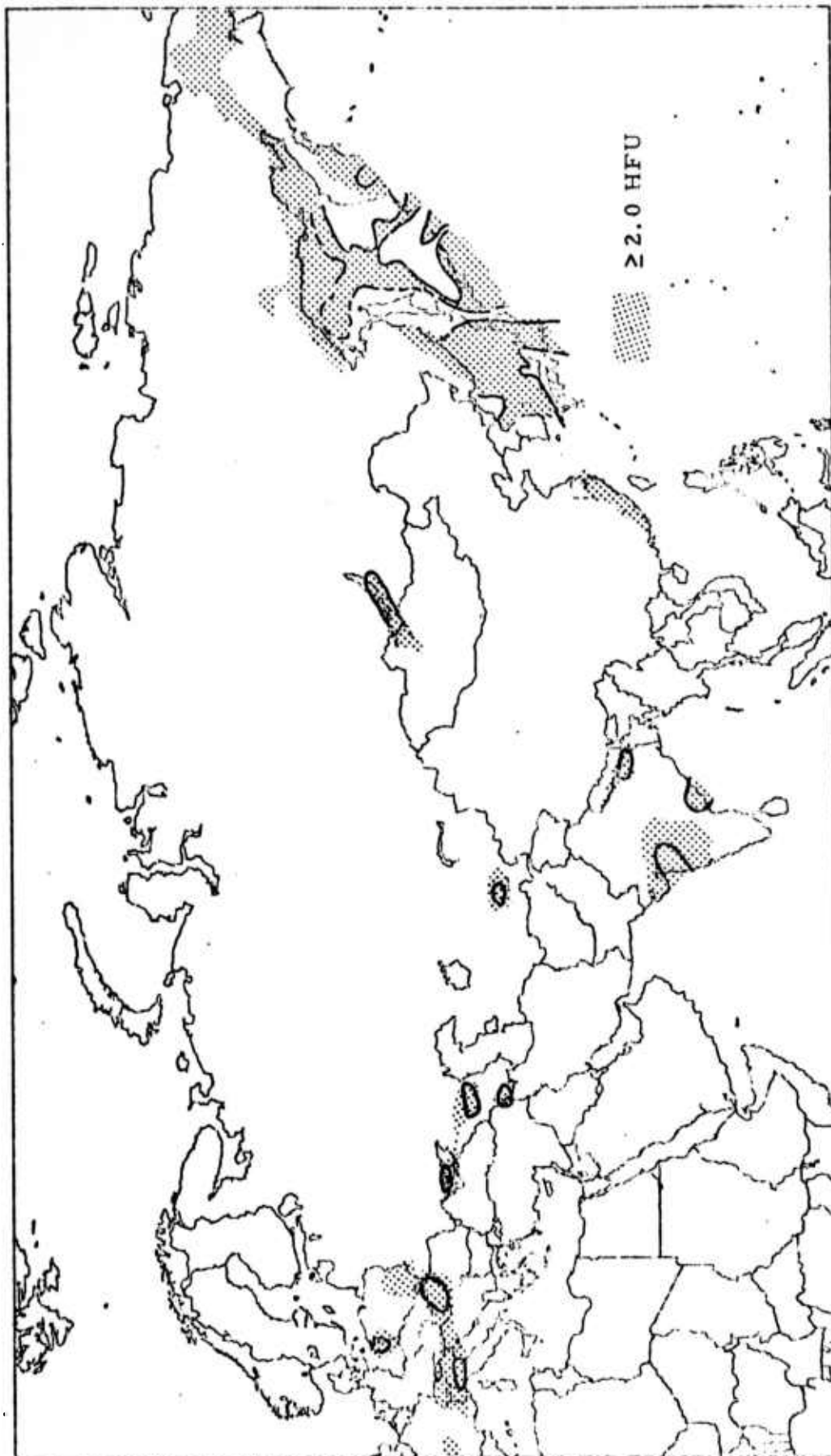


FIGURE 5
REGIONS OF HIGH HEAT FLOW IN EURASIA

are also shown which appear to be associated with the late teleseismic P-wave arrivals reported for the region by Herrin and Taggart. Localized high heat flow (>2.0 HFU) is also evident between the Caspian Sea and Black Sea in the Caucasus, along the northern part of the Black Sea, and very definitely in the Hungarian Basin and parts of East Germany.

Shield-platform-massif regions are virtually all represented by heat flow less than 1.5 HFU, and many values are less than 1.0 HFU. An exception is shown in India, where the broad shield area includes mostly values in excess of 1.5 HFU. This anomaly may be the result of selective location for the measurements, or possibly because of major world-tectonic influences.

Table I includes heat flow values obtained near stations where P-delays were measured, and a compilation of these two data sets are shown in Figure 6. As expected from observations in the U. S., higher heat flows correspond to relatively late P-wave arrivals, while low heat flow areas in the stable continental interiors are accompanied by earlier P-wave arrivals. A single point for Budapest (delay -0.4 seconds at 2.0 HFU) seems to disagree with the overall trend. The time delays were derived from 35 sources, and the heat flow probably represents the most thorough mapping of heat flow for any of the continental regions (Boldizar), so the bias caused by azimuthal considerations in the P-wave delays is the most obvious explanation. It is interesting to note that the spread in HFU for a given time delay is about one unit, and that the spread in times for a particular heat flow level is about 1.0 second where most of the data are concentrated. Part of the spread might be accounted for by separation of the actual geographic location of the observation points for the two types of measurements or by azimuthal effects upon the P-wave, but it also suggests that the tie between heat flow and P-delay is not strictly deterministic.

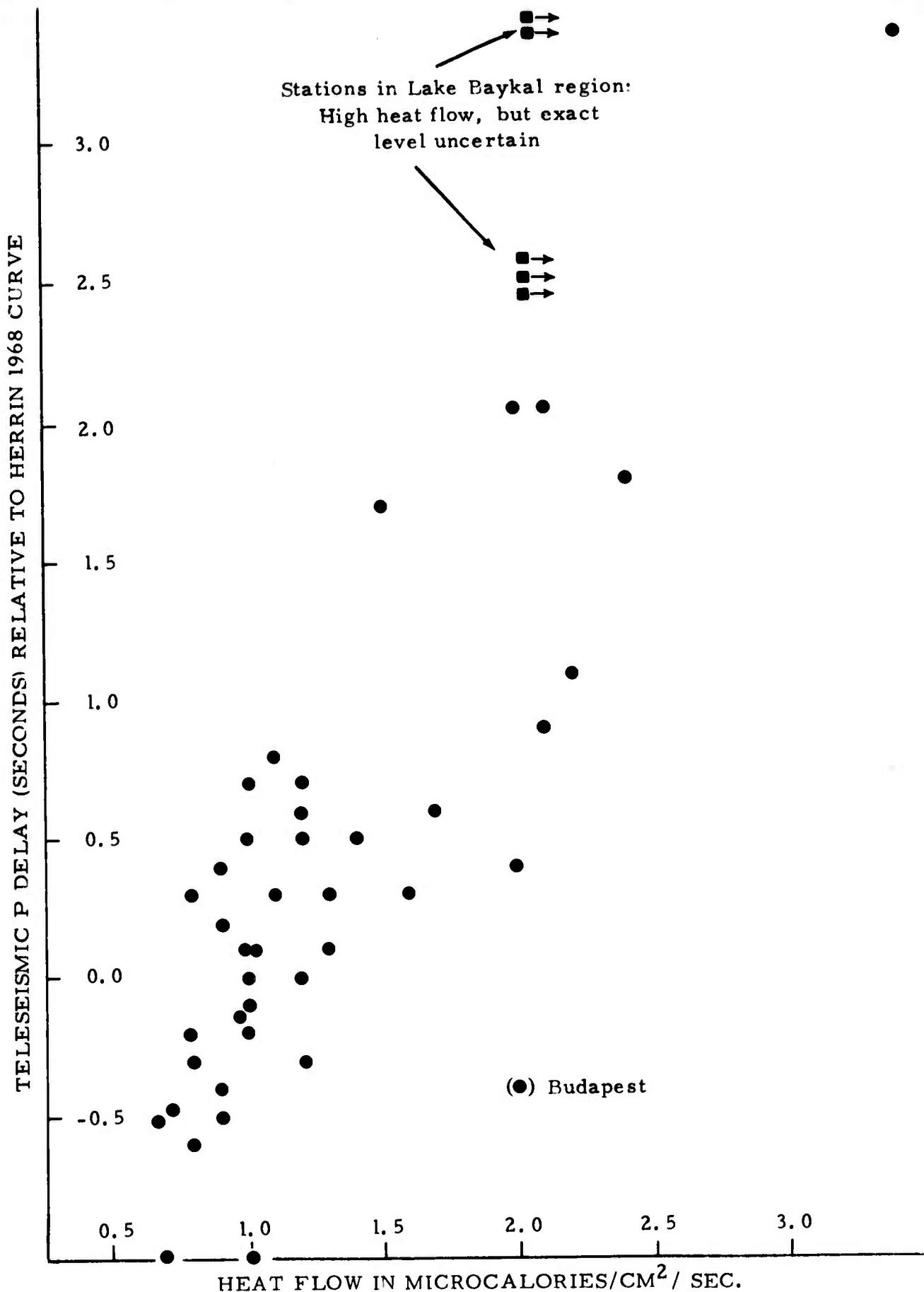


FIGURE 6
COMPARISON OF HEAT FLOW AND TELESEISMIC
P-WAVE DELAYS IN EURASIA

SECTION VI

LONG-PERIOD TELLURIC CURRENTS

The concept of utilizing telluric currents in connection with the other geophysical parameters compiled here is most simply expressed as an observation that a layer of high conductivity (or low resistance) at shallow depth (on the order of 30-40 kilometers) may be representative of partial melting and high ionic mobility in the upper mantle. By measuring the magnetic field induced by current flow in the crust and upper mantle at appropriate frequencies, the presence or absence of such a layer can be inferred from a rate of change in the field strength with change in frequency.

Such investigations in the U.S. show a correspondence of the inferred high conductivity layer at shallow depth, high heat flow, low Pn velocity, and late teleseismic P-wave delays.

Several regional and local USSR magnetotelluric surveys have been published with interpretations which expand the areas covered by P-delays, Pn velocity, and heat flow discussed earlier. No magnetotelluric data for China was found in the literature search. The surveys areas are shown on Figure 7 as cross-hatched or stippled for inferred lack of a shallow conducting layer in the upper mantle or its inferred presence, respectively.

The presence of materials in the upper mantle which are highly conducting is indicated in the Hungarian Basin (Berdichevskiy, et al 1971), in a very small area of the Ukrainian Shield (Rokityanskiy and Logvinov, 1972), in the southern Caspian (Berdichevskiy, et al, 1971), near Lake Baykal (Yanovskii, et al 1964) and in east-central Kamchatka (Kopytenko, et al 1967). No highly-conducting layer is found beneath the Kola Peninsula (Rokityanskiy, et al 1963),

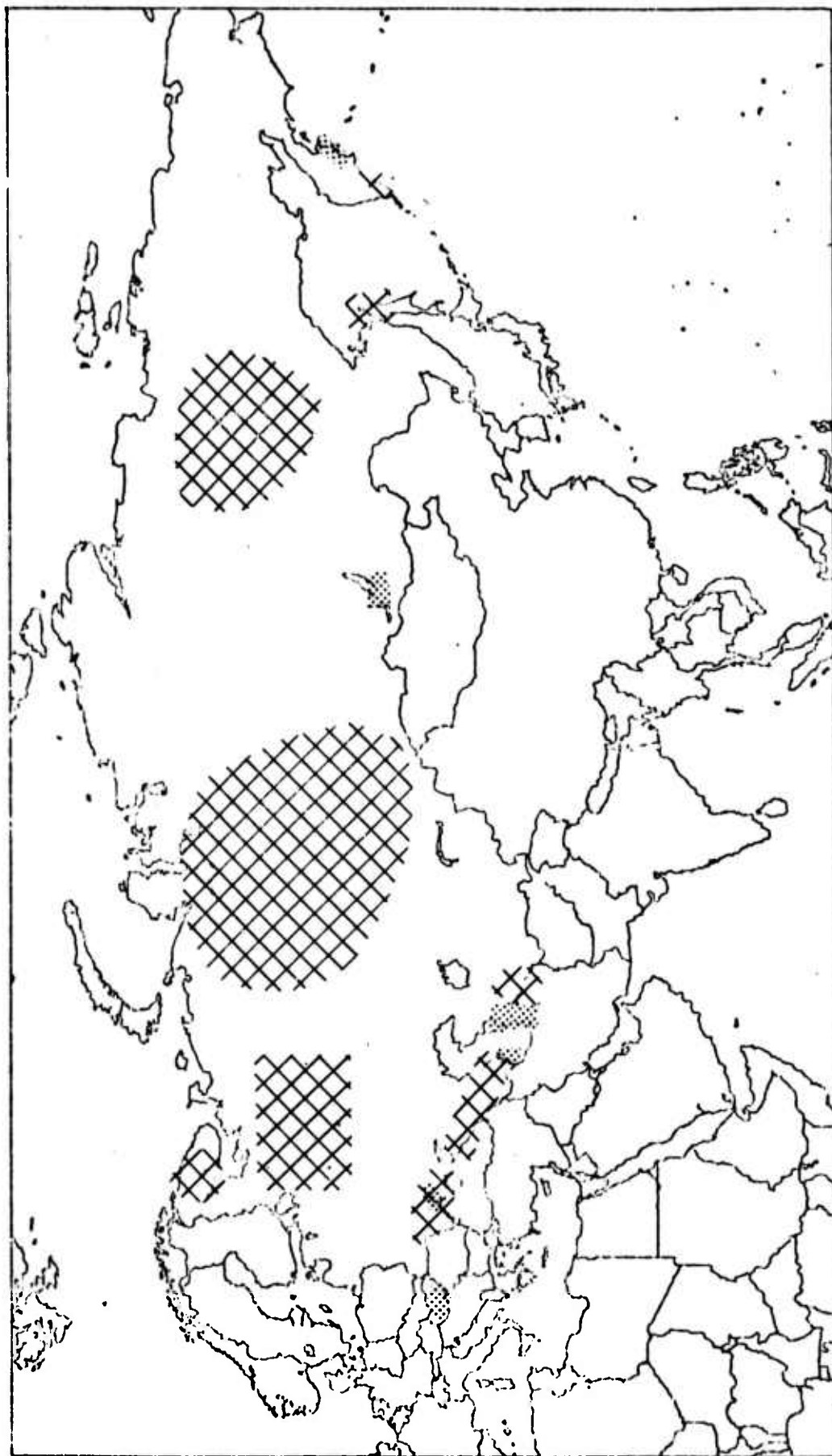


FIGURE 7

EURASIAN REGIONS REPORTED AS HAVING LOW OR HIGH CONDUCTIVITY AT SHALLOW DEPTH
(20-40 KMS) FROM MAGNETOTELLURIC SURVEYS IN EURASIA

in the central Russian Basin (Yanovskii, et al, 1964), most of the area on the Ukrainian Shield (Rokityanskiy and Logvinov), in Georgia (Kebuladze and Gugunave, 1970), east and north of the high conductivity area noted along the Caspian (Berdichevskiy, et al), virtually all of the West Siberian Lowlands (after Vashchilov, 1970 and 1971), "Yakutiya" in a broad region surrounding Yakutsk (Berdichevskiy, et al 1969), in northern Sakhalin (possible weakly conducting shallow layer, Berdichevskiy 1972), and beneath southeastern Kamchatka (Kopytenko, et al 1967).

Virtually all regions where heat flow is low, teleseismic P-delays are negative (early P-wave arrivals) and high upper mantle velocities are indicated include those regions where the absence of a shallow layer of low resistivity in the upper mantle is inferred. A similar parallelism is noted for high heat flow, slow P-waves and the presence of a shallow layer of high conductivity. There appears to be no reason to expect that these factors should be different on a geophysical basis since the same relationship was observed in the U. S. , and no apparent conflict in the Russian data exists in these terms.

SECTION VII

ESTIMATED UPPER MANTLE P-WAVE ABSORPTION (Q)

In the United States, increased absorption of seismic energy carried in compressional waves appears to accompany high heat flow, slow P-waves, and low resistance areas. Several of the refraction profiles reported in the Russian literature provide sufficient information to estimate upper mantle P-wave Q, but none were found for China. Estimates of Q from the Russian reports shown below are truly estimates, since no actual recordings were used and only average conditions are typically reported.

In all cases discussed below, P-waves are assumed to propagate as head waves with a geometrical amplitude decrease proportional to the inverse square of distance as an overriding consideration. All other amplitude decrease with distance is assumed to be caused by dissipation represented by Q. Many of the paths considered may not actually be represented by head wave propagation, but values in any particular region should reflect upper mantle characteristic changes, at least on a relative scale.

Three basic methods of estimating the Q were used for the upper mantle dissipation constant values: relative amplitudes (or relative average amplitudes), either from tabulations or scaled from figures in the reports cited, direct conversion from reported absorption constants; and conversion from the shape of P-wave spectral envelopes. Several values of upper mantle Q as calculated by the author cited are also included.

If A_0 is the amplitude of P-waves at the source for some average wave frequency f and the signal propagates as a head wave with average

velocity V , the amplitude A_r expected at some distance r from the source is:

$$A_r = A_o r^{-2} \exp - \frac{\pi f r}{QV} \quad (1)$$

This is the assumed relationship for estimates of Q given below. If an amplitude from stations near the source is given (or given for stations along a path approximately radial to the source), the relationship can be written

$$\frac{A_2}{A_1} = \left(\frac{r_2}{r_1}\right)^{-2} \exp - \frac{\pi f (r_2 - r_1)}{QV} \quad (2)$$

or,

$$Q = \frac{\frac{\pi f}{V} (r_2 - r_1) \log_{10} e}{\log_{10} \left(\frac{A_1}{A_2}\right) - 2 \log_{10} \left(\frac{r_2}{r_1}\right)} \quad (3)$$

where A_1 and A_2 represent the ground motion amplitudes of the signal at the same frequency at distances r_1 and r_2 , respectively.

A spatial coefficient of attenuation is sometimes reported in addition to a geometrical term, or both coefficients are combined in a single exponent α of the form:

$$A_r = A_o r^{-\alpha} \quad (4)$$

by equating the P attenuation coefficient above with that of (1), simple algebra provides the following (if head wave propagation is assumed):

$$Q = \frac{\pi f (r_2 - r_1) \log_{10} e}{V (\alpha - 2.0) \log_{10} \left(\frac{r_2}{r_1}\right)} \quad (5)$$

Finally, several of the reports encountered in the literature review included estimates of P-wave spectra and the shape of the spectral envelope. The fundamental description of Q is in terms of energy loss per cycle of motion (or per wave length along the propagation path). If the P-wave is considered a mode of non-dispersive propagation, the propagation velocity is not a function of frequency, but wave length is a function of frequency. In other words

$$V = f\lambda \quad V = \text{Constant} \quad (6)$$

where λ is wave length. More wave lengths of high frequency signal are included in a given wave path than low frequencies under this condition, and the rate of amplitude decrease per cycle may be estimated from spectra recorded at a single recording station. It is necessary to either assume that the signal energy at the source is the same over the frequency band of interest for their approach, or somehow account otherwise for spectral shape inherent in the source function. A "white" source is assumed for the data at frequencies less than the peak amplitudes recorded (usually about 1-4 seconds wave period for the data here).

Simple algebra involving (1) and (6) results in the frequency method of estimating Q at a single location from spectral estimates:

$$Q = \frac{(f_1 - f_2) \frac{\pi r}{V} \log_{10} e}{\log_{10} A(f_2) - \log_{10} A(f_1)} \quad (7)$$

where $A(f_1)$ and $A(f_2)$ are the spectral amplitudes (corrected for total system response) at frequencies f_1 and f_2 respectively. Figure 8 shows the general approach for estimating the spectral envelope of interest. Specifically, the slope angle is used to describe the envelope in terms which can be used directly in (7) above, noting that the frequency and amplitude difference can be used to describe the trigonometry of the angle ϕ .

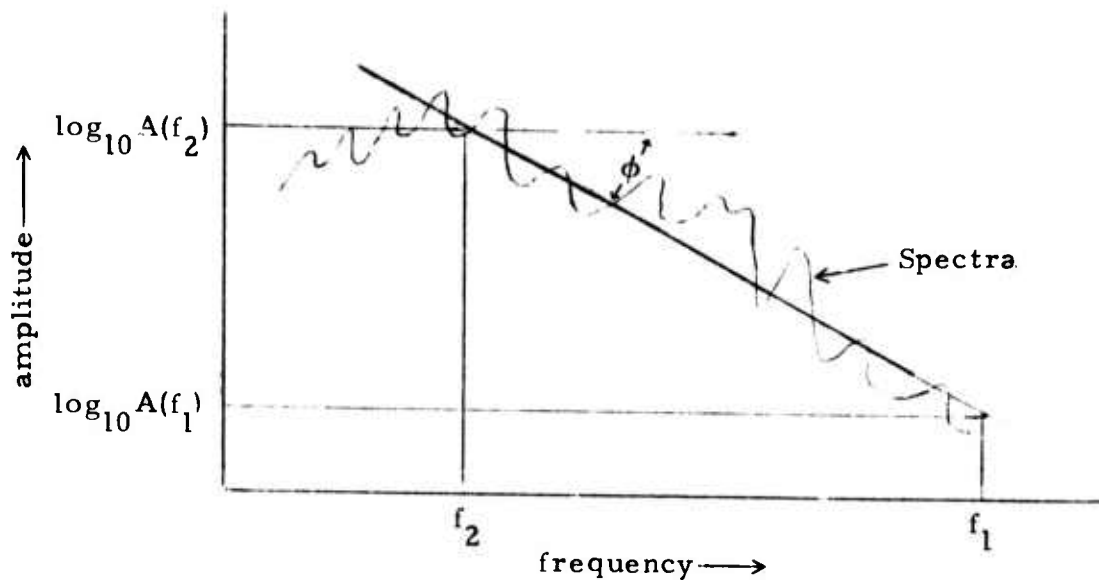


Figure 8

P-WAVE SPECTRAL ENVELOPE

Q may then be estimated from

$$Q = (\tan \phi)^{-1} \frac{\pi r}{v} \log_{10} e$$

$$\text{where } \tan \phi = \frac{\log_{10} A(f_2) - \log_{10} A(f_1)}{(f_1 - f_2)}$$

Note that the method is independent of a geometrical spreading term since all frequencies in the signal are assumed to follow the same path and are subject to frequency independent geometrical spreading influence.

Table II shows the methods and data sources for upper mantle Q calculated from Russian publications. Typical values from the table are plotted in Figure 9 as representative of the Q estimate for regions where data were available. With the exception of data from the Kamchatka-Kurils and an east-central Russian profile, the Q is based upon maximum amplitude of

TABLE II
CALCULATED UPPER MANTLE Q
(PAGE 1 OF 6)

BLACK SEA

(Neprochnov, et al, 1971)

$$Q = \frac{\frac{\pi f}{v} (r_2 - r_1) \log e}{\log \left(\frac{A_1}{A_2} \right) - 2 \log \left(\frac{r_2}{r_1} \right)}$$

Assuming frequency ~ 10-20 cps, from Figure 2

$$Q = \frac{6.8f}{.4} \approx 250 \text{ (on map)}$$

CAUCASUS

(Dzhibladze, et al, 1971)

$$Q = \frac{\pi f}{\alpha v} \quad v = 8.0 \quad f = 1.0 \text{ cps}$$

General only for Caucasus region (no paths available)

$$\begin{array}{lll} \alpha = 2.1 & r_2 - r_1 = 200-40 & Q(1.0 \text{ cps}) = 390 \approx 320 \text{ (on map)} \\ \alpha = 3.0 & r_2 - r_1 = 1000-300 & Q(1.0 \text{ cps}) = 228 \end{array}$$

KOPET DAG-ARAL SEA (Central Turkemania)

(Ryaboi, 1966)

$$Q = \frac{\frac{\pi f}{v} (r_2 - r_1) \log e}{\log \left(\frac{A_1}{A_2} \right) - 2 \log \left(\frac{r_2}{r_1} \right)} \quad \begin{array}{l} v = 7.9 - 8.2 \\ f = 12.5 \text{ cps} \end{array}$$

From Figure 1

sp 2680 profile	$r_2 - r_1 = 226-143 \text{ kms}$	$Q = 100$
sp 4150 profile	$r_2 = r_1 = 228-137 \text{ kms}$	$Q = 130$
sp 5270 profile	$r_2 = r_1 = 237-123 \text{ kms}$	$Q = 160$
sp 6620 profile	$r_2 = r_1 = 257-152 \text{ kms}$	$Q = 154$
(reversed)	226-66	$Q = 360 = 200$

TABLE II
CALCULATED UPPER MANTLE Q
(PAGE 2 OF 6)

CASPIAN-HINOUKUSH-SEMIPALATINSK

(Shamina, 1967)

Epicentral Region: 37.0 N 71.0 E, numerous observations, Q based on average of all observations.

Stations Khorog, Kulyab (KHO, KUL) reference amplitudes, Q computed to (and between) from Table II⁽¹⁾ and Figure 8⁽²⁾ (in the above reference).

KEY:

Frunze	FRU
Anctizhan	ANR
Alma-Ata	AAA
Semipalatinsk	SEM
Bairom-Ali	BAT
Askabad	ASH
Kizyl-Arvot	KAT

	(1)	(2)		(1)		(1)	(2)
KHO-KUL	71		KUL-ANR	53	FRU-SEM	410	155
-ANR	23	22	-FRU	109	AAA-SEM	670	hi Q
-FRW	840	hi Q	-AAA	138	BAT-KAT	hi Q	
-AAA	566	252	-SEM	233	-ASH	352	
-SEM	114	114	-BAT	93	ASH-KAT	1200	
-BAT	375	338	-ASH	185	ANR-FRU	hi Q	
-ASH	368	210	-KAT	405			
-KAT	hi Q	hi Q					

Averages

KHO, KUL-ANR	30
KHO, KUL-FRU	800
KHO, KUL-AAA	325
KHO, KUL-SEM	150 (strong absorption to ANR along path)

TABLE II
CALCULATED UPPER MANTLE Q
(PAGE 3 OF 6)

GARM REGION

(Ryaboi, 1966)

$\alpha = 3.5, 4.0$	$r = 250-50$	$Q = 32, 24$	} Agrees with KHO:KUL-ANR
$\alpha = 5.7$	$r = 250-700$	$Q = 46$	

EAST-CENTRAL ASIA (W. Siberia, Urals, Russian Platform)

(Passechnik, 1960)

Assumed path from Pokrovsk-Uralskii toward Semipalatinsk (could be toward Kopet-Dag).

$$r_2 - r_1 = 1000-200 \text{ kms,} \quad v = 8.0, \quad f = 1.0 \text{ cps}$$

Q_{pn} first motion = 235

Q_{pn} max amplitude = 930 (on map)

KAMCHATKA-KURIL-SAKHALIN-EASTERN RUSSIA

(Kondorskaya, et al, 1967)

Assumes r^{-2} geometrical divergence in all cases (even with distances which may exceed Pn path assumption).

Stations

PET	Petropavlosk Kamchatsky
SKR	Severo-Kurilsk
UGL	Uglegorsk
YSS	Yuzhno-Sakhalinsk
KUR	Kurilsk
OKH	Okha
MAG	Magadan
SIU	Shimushu
VLD	Vladivostok
YAK	Yakutsk

TABLE II
CALCULATED UPPER MANTLE Q
(PAGE 4 OF 6)

Sources for the Following List

1 - 17	Shallow Aleutian Islands	$h < 30 \text{ kms}$
18 - 26	Shallow Kamchatka	$h < 60 \text{ kms}$
27 - 33	Deeper Kamchatka	$60 < h < 170$
34 - 41	Shallow Japanese	$h < 30$

Data taken from Table 1, spectral method for amplitude spectra corrected for system response

$$Q = \tan \alpha \frac{\pi r}{v} \log e$$

$$v = 8.0 \text{ km/sec.}$$

r in km

$\Delta < 25^\circ$ only

<u>EVENT</u>	<u>STATION</u>	<u>Δ°</u>	<u>TAN α</u>	<u>Q</u>
3	PTR	13.2	1.0	250
	MAG	18.2	.69	500
	KUR	22.3	1.35	310
	YSS	24.7	.50	970
6	PTR	20.0	1.27	300
	MAG	23.7	1.60	280
7	PTR	21.2	1.08	370
8	PTR	13.8	1.02	250
	KUR	23.0	.83	520
	UGL	25.0	.88	530
	YSS	25.5	1.19	400
9	PTR	21.8	1.40	290
	MAG	24.7	1.08	430
10	MAG	24.3	1.10	410
11	PTR	20.9	1.27	310
12	PTR	15.9	1.14	260
	MAG	20.4	1.13	340
13	PTR	20.6	1.72	220
14	SKR	13.0	1.26	190
15	PTR	17.4	1.06	310

TABLE II
CALCULATED UPPER MANTLE Q
(PAGE 5 OF 6)

<u>EVENT</u>	<u>STATION</u>	<u>Δ°</u>	<u>TAN α</u>	<u>Q</u>
17	OKH	23.0	.74	580
20	PTR	4.3	1.08	70
	UGL	15.4	1.42	200
	YSS	16.1	.86	350
21	KUR	11.6	1.74	120
23	OKH	10.3	.94	210
	UGL	12.4	1.28	180
	YSS	13.2	.83	300
	VLD	21.6	1.03	390
24	SKR	5.0	1.02	90
25	SKR	5.5	.88	120
	MAG	8.2	.90	170
	VLD	23.0	1.42	300
27	MAG	6.5	.70	170
	UGL	14.0	.95	530
	YSS	15.0	1.08	260
28	MAG	7.6	.95	150
	UGL	11.4	1.28	170
	YSS	12.4	1.06	220
	VLD	20.7	1.12	350
29	PTR	3.3	.38	160
	MAG	7.1	.74	180
	UGL	13.8	.76	340
	YSS	14.5	1.01	270
	VLD	23.0	1.20	360
30	MAG	7.5	.66	210
	UGL	12.3	1.06	220
	YSS	13.0	1.88	130
	YAK	17.5	1.78	190
	VLD	21.5	.56	720
31	MAG	7.7	.40	360
	UGL	11.2	.60	350
	YSS	11.8	1.25	180
	VLD	21.0	1.16	340
32	MAG	8.5	.33	480
33	VLD	19.5	.46	800
	YAK	18.5	1.60	220

TABLE II
CALCULATED UPPER MANTLE Q
(PAGE 6 OF 6)

<u>EVENT</u>	<u>STATION</u>	<u>Δ°</u>	<u>TANα</u>	<u>Q</u>
35	KUR	8.5	1.22	130
	UGL	10.2	1.34	140
	PTR	19.1	1.08	330
36	UGL	9.1	1.35	130
	SKR	12.0	1.34	170
37	KUR	6.5	1.22	100
	UGL	9.1	.46	370
	SKR	14.0	.84	310
38	OKH	12.7	.72	330
39	KUR	10.3	1.14	170
	SIU	13.0	1.18	210
	OKH	14.3	1.08	250
40	OKH	17.3	1.40	230

AVERAGES FOR KAMCHATKA-KURIL Q VALUES				
<u>STATION</u>	<u>ALEUTIANS</u>	<u>KAMCHATKA-KURILS</u>		<u>JAPAN</u>
		<u>Shallow</u>	<u>Deep</u>	
MAG	440	180	430	—
PET	290	70	160	330
KUR	410	120	—	170
YSS	700	330	<u>250</u> 150	—
UGL	520	190	290	210
SKR	190	200	—	240
VAK	—	—	200	—
VLD	—	350	<u>740</u> 340	—
OKH	580	210	—	270
SIU	—	—	—	210

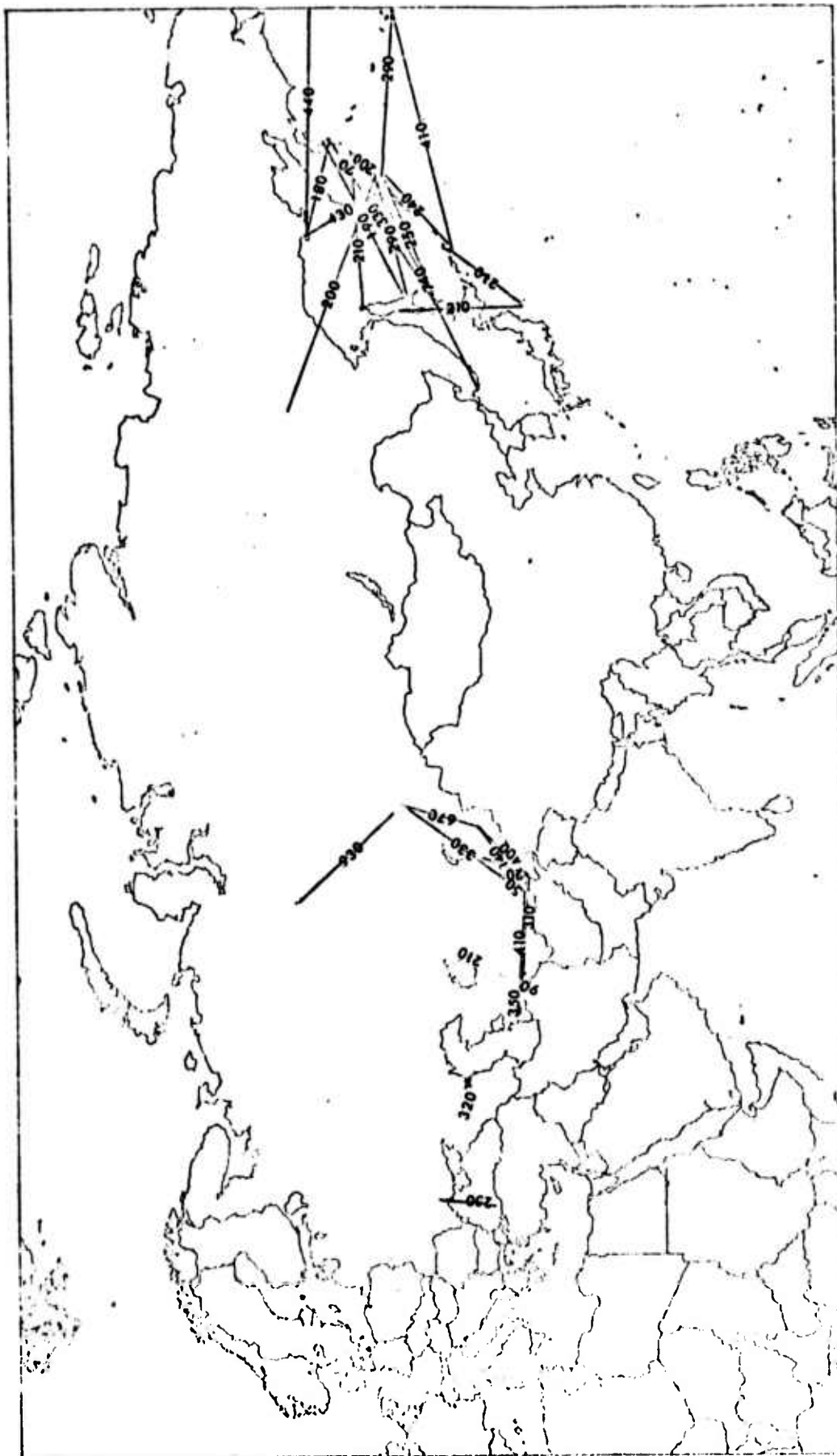


FIGURE 9
CALCULATED UPPER MANTLE Q FOR EURASIAN PROPAGATION PATHS

Pn, rather than first motion of the signal. The first motion energy is dissipated much more rapidly, probably because of signal energy loss in high frequencies. Maximum amplitude dissipation is important in terms of describing signal detectability and so these data are also of interest.

Values of Q calculated from the reports agree with conditions expected from observations of the other geophysical parameters. Low Q (less than 100) is found where high heat flow, late teleseismic P-waves, slow Pn velocity, and suggestions of partial upper mantle melting from magnetio-telluric data are observed. One possible contradiction is found in a profile through the Black Sea, but amplitude data reported there were from acoustic observations taken near the sea bottom and therefore may not be very accurate amplitude observations. Higher values of Q correspond to those regions which are usually termed stable continental cores (shields, platforms, and massifs), and intermediate values (100-300) are found in structurally active areas.

Details in the Kamchatka-Kurils region are about as expected. In particular, Q for paths to Magadan are interesting in that the Q calculated for signals coming from the Aleutians passing beneath Kamchatka is relatively high (440) as is the Q for signals with sources deep beneath Kamchatka. However, shallow events beneath Kamchatka result in signals recorded at Magadan which pass through some zone of high attenuation, and Q for the total path is low (180). The suggestion of a zone of partial melting beneath Kamchatka is strong from the Q observed as well as other geological-geophysical evidence. This feature probably also has a strong influence on the Q calculated for the path from Kamchatka to Yakutsk on the platform of eastern Russia.

This same condition is evident beneath the southern Kuril Island of Etorofu, where Fedotov and Boldyrev (1969) report a zone of low Q (30-50) between 55 and 150 Kilometers depth for 1.25 cps waves. Q for higher

frequencies (20 cps) is on the order of 200-300, suggesting that these waves may be propagating in the "cold downgoing slab" proposed in models of global tectonics.

SECTION VIII

SUMMARY

Data from Eurasian sources appear to coincide with observations in the U. S. and other regions in terms of the qualitative corroborations found among geotectonics, P-wave velocities in the upper mantle, heat flow from within the earth, telluric current influences, and P-wave absorption. The broad continental structural platform comprising most of the USSR is apparently supported by a relatively stable and rigid upper mantle where high P-wave velocities and low absorption for P-wave energy is representative. Around the peripheries of this broad region are localized zones of slow velocities and strongly absorptive characteristics. No broad region of high attenuation similar to the Basin and Range Province of the U. S. is evident, unless the Sea of Okhotsk-Sea of Japan-Kuril-Kamchatka region is representation of that province for Eurasia.

With the exception of areas around Lake Baykal and some of the small platform basins of South Central USSR, the high P-velocity-low absorption regions extend from the northern limits of the land mass to the front of the mountain ranges in southern Russia, and to the southern parts of the Caspian and Black Seas. Based upon the patterns of P-delays, northeastern China is similar in character, but P-wave absorption and heat flow probably increase toward western and southern China while upper mantle P-velocity should decrease. The complexities of the Himalayan regions are not resolved in the data on hand to any great extent. Heat flow in India is enigmatic to this writer, since the shield area should be considerably cooler and show less positive P-delays on the basis of observations on all other shield areas. The unique interpretation of the role of India in global tectonics as a battering ram on southern Eurasia may be related to this situation.

Details of heat flow and P-wave absorption in the eastern or border regions of Eurasia generally conform to observations of similar tectonic regions along the Pacific borders, with high heat flow and strong energy absorption beneath the Peninsula and island chain. The overall tectonic activity of the region would imply that local variations should exist, and variability in both factors within the regions seem to agree with such an implication. Relatively few teleseismic P-delays are available for interpretation here, but these are also somewhat variable. Numerical values of absorption calculated here agree with those published by the Russian research groups, and there seems to be no reason to suspect that the tectonic effects of the island arc are different here than for similar regions elsewhere.

A regional map of estimated upper mantle Q for P-waves beneath Eurasia is given in Figure 10 based upon the available data. The map cannot be considered a definitive display of values of Q, but should be used as a regional estimate which represents the best estimate derived from rather scanty data and subjective extrapolation over a very large geographic area. General characteristics of the relative upper mantle Q distribution beneath Eurasia are represented, however, and the map can serve as a guideline for further detailed analysis and corroboration for surface wave Q studies.

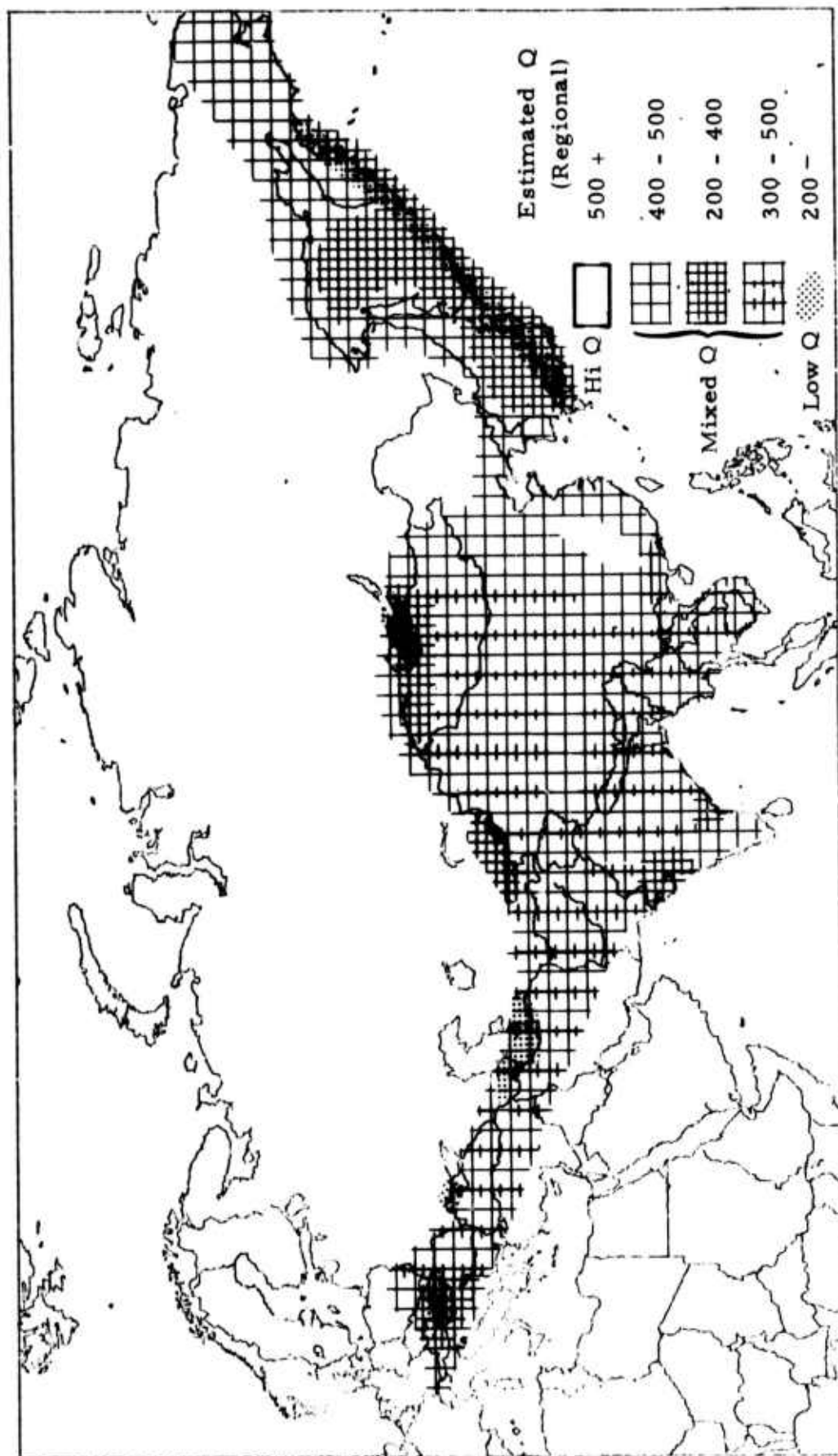


FIGURE 10
ESTIMATED UPPER MANTLE Q FOR P-WAVES BENEATH EURASIA

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